

Analysis of heavy fuel oil use by ships operating in Canadian Arctic waters from 2010 to 2018

Nicolien van Luijk^{a*}, Jackie Dawson^a, and Alison Cook^a

^aDepartment of Geography, Environment and Geomatics, University of Ottawa, Ottawa, ON K1N 6N5, Canada

*nvanluij@uottawa.ca

Abstract

In 2018, The International Maritime Organization, officially proposed consideration of a ban on heavy fuel oil (HFO) use by ships in the Arctic, because of the widely accepted understanding that HFO presents a threat to the marine environment. There is currently a lack of understanding of the scale and scope of HFO use by ships operating in Canadian Arctic waters, thus it is difficult to comprehensively evaluate the effect that such a ban may have in mitigating risk from HFO use. In this study, we conducted a spatial analysis of HFO use among ships operating in Canadian Arctic waters between 2010 and 2018. Our findings show that approximately 37% of the total number of ships that have travelled through the Canadian Arctic between 2010 and 2018 use HFO, and nearly all of these ships fall within three vessel categories: general cargo, bulk carriers, and tanker ships. In addition, HFO-fueled ships made up approximately 45% of the total distance (kilometres) travelled by all vessels between 2010 and 2018. The data also show that the majority of HFO use occurs in certain geographic areas, such as Baffin Bay near Pond Inlet and the Hudson Strait.

Key words: heavy fuel oil, Canadian Arctic, shipping, Arctic communities, environment, climate change



Citation: van Luijk N, Dawson J, and Cook A. 2020. Analysis of heavy fuel oil use by ships operating in Canadian Arctic waters from 2010 to 2018. FACETS 5: 304–327. doi:[10.1139/facets-2019-0067](https://doi.org/10.1139/facets-2019-0067)

Handling Editor: Neil Cameron Swart

Received: December 20, 2019

Accepted: February 20, 2020

Published: May 14, 2020

Copyright: © 2020 van Luijk et al. This work is licensed under a [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/) (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

Published by: Canadian Science Publishing

Introduction

The International Maritime Organization (IMO), at the 72nd session of the Marine Environment Protection Committee, directed the sixth session of the Pollution Prevention and Response Subcommittee to develop a ban on heavy fuel oil (HFO) use by ships in the Arctic, on the basis of an assessment of the impacts and on an appropriate timescale. It is vital that research on the extent of use and on the impacts of HFO be conducted so that international decision-making can make specific policy decisions and directives that are indeed evidence based. Some research has already been conducted about HFO use in the Arctic ([Det Norske Veritas 2011](#); [Comer et al. 2016](#)) including a few studies that focused directly on the Canadian Arctic ([Vard 2016](#); [DeCola and Robertson 2018](#)). The World Wildlife Fund Canada has commissioned and conducted studies that examine the potential impact of HFO use in Canadian Arctic waters and the potential costs of an HFO ban on Canadian Arctic communities that rely on cargo ships for their annual resupply ([Vard 2016](#); [DeCola and Robertson 2018](#)). In addition, in December 2019, Transport Canada released a report assessing the benefits and impacts associated with a proposed ban on HFO in the Canadian Arctic ([Transport Canada 2019](#)). While it is widely accepted that HFO presents a threat to the marine environment,

there is a lack of understanding of the scale and scope of HFO use by ships operating in Arctic waters; therefore, it is difficult to discern the extent to which the proposed ban may affect ship operations in the region. However, there is an overall significant lack of scientific understanding of the specific effects of HFO in Arctic waters and, importantly, there are significant knowledge gaps on the potential implications of an HFO ban for ship operators and local communities in Canada.

In this study, we focus solely on understanding the scale and scope HFO use among ships operating in Canadian Arctic waters and do not comment on the potential implications of the proposed HFO ban. To establish the scale and scope of HFO use among ships operating in Canadian Arctic waters we utilized a variety of research methods to develop a database of fuel use by ships that operated in Canadian Arctic waters between 2010 and 2018. The database was then used to determine the type and size of ships that are most likely using HFO and to determine where (spatially) these ships are travelling within the Canadian Arctic. Before presenting the study methods and results, we provide an overview of HFO use and its potential impacts on the marine environment, briefly touch on policy discussions regarding HFO use in the Arctic and Canadian Arctic specifically, and reflect on the potential impacts a ban could have on Canadian Arctic communities. Further, we consider previous research that has examined HFO in the Arctic to provide the context for our study and methods.

State of knowledge

HFO and shipping

It is widely accepted that a marine oil spill presents one of the most significant threats to the Arctic marine environment (AMSA 2009; Comer et al. 2016; Fritt-Rasmussen et al. 2018; Prior and Walsh 2018) and that HFO (also known as heavy grade oil, residual fuel, or crude oil) is particularly harmful when compared to other fuels that are typically used in the Arctic today (Browning et al. 2012; Fritt-Rasmussen et al. 2018). HFO presents the potential for harm to the marine environment in the case of an oil spill, and another concern is the amount of pollutants it releases into the air, which can be harmful to both the environment and to human health (Browning et al. 2012; Oeder et al. 2015; Fritt-Rasmussen et al. 2018; Prior and Walsh 2018).

HFO is a popular marine fuel because it is one of the cheaper fuels and is also readily available. Most large commercial ships (e.g., general cargo, bulk carriers, and tanker ships) operate on HFO, whereas smaller ships (e.g., tugs, expedition style passenger ships, and fishing vessels) tend to use more refined fuels such as marine diesel oil or marine gas oil (also known as distillate fuel) (Comer et al. 2016). Distillate fuel is a distilled and purified version of crude oil, and residual fuel (i.e., HFO) is what is left over after this distillation process. Thus, residual fuel is less refined, thicker, and contains more impurities than distillate fuel. HFO can sometimes contain a mixture of residual and distillate fuels, and this is known as intermediate fuel oil (IFO). HFO has been defined by The International Convention for the Prevention of Pollution from Ships as:

... crude oil having a density, at 15 °C, higher than 900 kg/m³; oil, other than crude oil, having a density at 15 °C, higher than 900 kg/m³ or a kinematic viscosity, at 50 °C higher than 180 mm²/s; or bitumen, tar, and their emulsions. (Det Norske Veritas 2011, p. 45)

Studies have shown that “a switch from residual to distillate fuel reduces BC [black carbon] emissions by at least 33%” (Lack 2017, p. 2). Det Norske Veritas (2019) also noted that using distillate fuels will reduce particulate matter and sulphur oxide by 67% and 94%, respectively. Reducing these emissions will have an immediate impact “on shipping’s overall global warming effects” (Det Norske Veritas 2019, p. 19). Researchers have argued that switching away from HFO can ease some of the potential environmental impact of oil spills as HFO is the most difficult fuel to clean up after a spill because

of its viscosity (Fritt-Rasmussen et al. 2018). HFO is even more challenging to clean up in ice-infested waters that are typical of the Arctic compared with warmer waters in more southern regions (Niu et al. 2014; Roy and Comer 2017). An HFO spill could have impacts on the marine environment for many years and could present substantial threats to any wildlife in the area (Prior and Walsh 2018). It is important to point out that while researchers argue that the environmental harms of HFO outweigh the harms caused by distillate fuel, distillate fuels also still create pollutants that harm the environment and affect human health (Corbett and Winebrake 2008; Oeder et al. 2015). While distillate fuel significantly reduces sulphur emissions, and some of the emissions of particulate matter (Corbett and Winebrake 2008), some researchers have found that distillate fuel creates a higher soot content that can have harmful effects on human health (Oeder et al. 2015). Thus, in addition to fuel ban proposals, researchers have argued for continued study and technological and policy innovations aimed at reducing particulate matter emissions in distillate fuels (Winnes and Fridell 2009). Distillate fuel is not the only alternative to HFO, there are other alternatives that have the potential to produce less air pollution and decrease the potential for damaging oil spills, such as liquid natural gas (LNG), battery-powered or solar-powered ships, and other types of cleaner fuels (Det Norske Veritas 2019). However, distillate fuel is currently the most feasible alternative for most ship operators in the Arctic considering its availability and reasonable cost (Det Norske Veritas 2019).

As HFO presents a recognized threat to the Arctic environment, many organizations, researchers, and Inuit organizations and communities are discussing the potential for, and implications of, implementing an Arctic-wide HFO ban on shipping. (The proposed ban for HFO in Arctic waters is for use and carriage for use, transportation of HFO as cargo is not included in this proposed ban.) HFO is already banned in certain marine areas around the world, for example, in Antarctic waters, and it is also restricted in Norwegian waters around Svalbard. However, discussions about a potential ban in the whole of the Arctic are ongoing and politically complex. The implementation of such a ban presents some unique challenges for Canadian Arctic communities, as it has the potential to increase the cost of resupply goods that many communities rely on. The Canadian government, Inuit Organizations, and Arctic communities in the region have raised concerns about this potential impact of an HFO ban on food security and food prices and have requested that additional research be conducted and that mechanisms be put into place to limit or eliminate this risk.

HFO and Arctic policy: Canadian perspectives

In December 2016, in a joint United States–Canada Arctic Leaders’ Statement made by then President Barack Obama and Prime Minister Justin Trudeau, the two leaders made a commitment to phase down the use of HFO in the Arctic (United States–Canada Joint Arctic Leaders’ Statement 2016). At the 72nd Marine Environment Protection Meeting in April 2018, Finland submitted a plan to ban the use and transport of HFO by ships in Arctic waters by 2021 (MEPC 72/11/1 2018). This proposal was supported by Iceland, Norway, Sweden, and the U.S. Non-Arctic states including Germany, the Netherlands, and New Zealand also supported the proposed ban. The Russian Federation responded to the proposed HFO ban by raising concerns about the economic impacts and recommended that all possible measures to mitigate an HFO spill should be explored prior to the implementation of a full ban (MEPC 72/17 2018). Canada, with the support of the Marshall Islands, submitted a proposal in 2018 in response to the proposed ban, outlining that the nations’ objectives were consistent with mitigating the risk of oil spills and harm to the Arctic environment, but requested that the potential impacts of an HFO ban on Arctic communities and economies be considered before full enactment (MEPC 72/11/4 2018). By February 2019, when the IMO announced that it would be working towards developing an HFO ban in Arctic waters, Canada and Russia remained the only two Arctic countries that had not provided an official position on the ban (George 2019a). In December 2019, the United States and Norway released the findings of studies examining the

potential impacts of an HFO ban on their respective marine areas located within the Polar Code (IMO PPR7/INF.14 2019; IMO PPR7/INF.19 2019). In February 2020, Canadian media revealed that the Canadian Government was set to announce its support for the HFO ban “with certain caveats” at the next IMO meeting to be held 17–21 February 2020 in London, UK. Transport Canada has not yet publicly shared this position at this time (Sevunts 2020).

The Inuit Circumpolar Council (ICC), a multinational nongovernmental organization representing Inuit of Alaska, Canada, Greenland, and Chukotka (Russia), has stated its official support for a ban on HFO that also minimizes the negative impacts that may be present for Arctic communities. During a media interview, ICC (Canada) Vice-President, Lisa Koperqualuk, pointed out “that over 50% of the daily Inuit diet comes from the land and sea. The value of a clean environment and sea ice cover is immeasurable. An HFO spill would put these community values at significant risk...” (ICC 2019, para. 5). Despite the potential impacts on resupply costs, other Inuit representative organizations have also come out in support of the proposed ban. On 25 October 2018, at their Annual General Meeting, Nunavut Tunngavik Inc. (NTI) also provided their support and encouraged the Canadian Government to ban HFO in Arctic waters (George 2018). NTI is the legal representative of the Inuit of Nunavut and “coordinates and manages Inuit responsibilities set out in the Nunavut Agreement and ensures that the federal and territorial governments fulfill their obligations” (NTI n.d.).

Other international nongovernmental organizations as well as some shipping companies have also announced support for an HFO ban in the Arctic. For example, the Arctic Commitment, which calls for a “phase-out of the use of heavy fuel oil by ships in a timely manner and [to] URGE International Maritime Organization Member States and stakeholders to advance this goal” (The Arctic Commitment 2017, para. 1) was signed by many organizations including the Clean Arctic Alliance, The International Cryosphere Climate Initiative, the ICC, alongside a number of conservation organizations from around the Arctic. Some cruise ship operators have also signed onto the Commitment, including Hurtigruten, Adventure Canada, and Ocean Expeditions. Most recently in November 2019, a 30-member Association of Arctic Expedition Cruise Operators (AECO) announced that its members would no longer use HFO on their ships (AECO 2019). It is notable however, that many ship operators, including members of AECO, that have come out in support for an HFO ban are not currently utilizing HFO in their operations and therefore will not be impacted (financially or otherwise) by a possible ban.

Not surprisingly, not all ship operators support an HFO ban in the Arctic. In 2017, a representative from Nunavut Eastern Arctic Shipping (NEAS), one of the regional Canadian Arctic shipping companies supplying sealift resupply to local Arctic communities, told media that an HFO ban could increase sealift costs for communities. A Nunavut Sealink and Supply (NSSI) representative also explained that NSSI would not absorb all the increased costs and would adjust the rate of sealift costs as needed (George 2017). These are the potential economic impacts that the Government of Canada raised in response to the proposed HFO ban. It is not clear what the exact costs will be; although, in December 2019 Transport Canada released a report that estimated the increase in resupply costs if a fuel switch from HFO to distillates would occur. They estimated that freight rates could increase between 1.13% and 1.20%, they also estimated that the costs of community resupply products could increase between 0.07% and 1.9%, which could increase household expenditures by CAD\$248–\$679 per household per year (Transport Canada 2019, p. 12). ICC Canada has emphasized that communities do not want to be, and should not be, the ones to shoulder these costs. Any increase in the cost of goods (food, fuel, other) in the region could have major implications for the well-being of Canadian Arctic communities considering the already high costs and the existing disparities in the region related to health and income inequality compared with Canadian averages (Power 2008;

Ford 2009). It is unclear how these additional costs will be dealt with in Arctic Canada if the HFO ban comes into force.

HFO and Arctic shipping research

While little research has been conducted on the use of HFO in the Canadian Arctic specifically, there are some detailed studies on HFO use across the Arctic more broadly. Comer et al. (2016) examined HFO use in the Arctic for 2015. They used the IMO's definition of the Arctic, which would be the area affected by the HFO ban if that were to take place. They found that 2086 ships travelled through this area in 2015 and estimated that 42% of this fleet would have used HFO, and that HFO also represented 57% of fuel used by weight (Comer et al. 2016). The report used data from the IHS Markit ship characteristics database ([ihsmarkit.com/index.html](https://www.ihs.com/markit/index.html)) and Automatic Identification System (AIS) data to determine fuel use for each ship entering the Arctic. Another study that examined HFO use in the Arctic was conducted by Det Norske Veritas (DNV) for Protection of the Arctic Marine Environment (PAME; a working group of the Arctic Council) in 2010. This report also utilized AIS data to obtain ship traffic information between August and November in 2010. DNV had access to the Veritas Petroleum Services database; this is a private fuel quality testing service that stores information about fuel use. Their findings indicate that 189 of 954 (approximately 20%) vessels operating through the Arctic region through August and November 2010 were capable of operating on HFO (Det Norske Veritas 2011). In the second phase of the study they examined HFO again, this time for a full calendar year. They found that in 2012, of the 1347 unique vessels operating in the Arctic, 28% were most likely using HFO (Det Norske Veritas 2013).

In a Canadian-specific scoping study, World Wildlife Fund Canada estimated fuel use by vessels operating along the northern Northwest Passage route in the Canadian Arctic as well as local traffic among several Nunavut communities using AIS data for the single year of 2016, found that “of the 123 transits mapped, approximately half of the vessels were burning a residual fuel (HFO or IFO), and that the other half used distillate fuels (MDO)” (DeCola and Robertson 2018, p. 8).

Canadian Arctic shipping—context

Over the past decade, all ship traffic in Arctic Canada has nearly tripled (Dawson et al. 2018) and further growth is expected given increased accessibility and open water season length due to climate change (Smith and Stephenson 2013; Stephenson et al. 2013; Pizzolato et al. 2016). However, compared with other Arctic regions globally, the Canadian Arctic attracts a relatively small number of vessels (AMAP 2017). Canadian Arctic communities are reliant upon marine vessels to provide community resupply (Pelletier and Guy 2015), to contribute to the local economy (tourism, mining, and fishing), and for traditional activities such as subsistence harvesting. There is also an increasing number of mines throughout the Canadian Arctic that rely on resupply, and some use ships to carry mined goods through the Arctic (Babb et al. 2019). The type of ships found in the Canadian Arctic are provided in Table 1.

Despite intense public interest in discussions around a potential HFO shipping ban in Arctic waters, we currently do not have any detailed insight into the temporal and spatial use of fuel types, including HFO use, among ships operating in Arctic Canada. This lack of understanding severely limits a full and evidence-based understanding of the potential implications (positive or negative) of the proposed HFO ban in Arctic waters. Thus, the goal of this study was to reveal the temporal and spatial rates of HFO use in the Canadian Arctic between 2010 and 2018. The study provides new insights on how much and where HFO has been used in the Canadian Arctic over time. The information may be useful in providing context to public and policy discussions on the HFO ban for ships operating in Arctic waters.

Table 1. Arctic Marine Shipping Assessment (AMSA) class description for ships.

AMSA class	Description	Examples
Bulk carriers	Bulk carriage of ore	Timber
		Oil, ore
		Automobile carriers
Fishing vessels	Fishing boats used in commercial fishing activity	Small fishing boats
		Trawlers
		Whaling boats
General cargo	Carries various types and forms of cargo	Fish-processing boats
		Community resupply
		Roll-on or roll-off cargo
Government vessels and icebreakers	Designed to move and navigate in ice-covered waters	Coast guard
		Icebreakers
		Research vessels
Oil and gas exploration vessels	Designed specifically for the exploration and extraction of natural gas and oil	Seismic, oceanic, and hydrographic survey vessels
		Oil, drilling, and storage vessels
		Offshore resupply
Passenger ships	Ships that carry passengers for remuneration	Portable oil platform vessels
		Cruise ships
		Ocean liners
Pleasure craft	Recreation vessels that do not carry passengers for remuneration	Ferries
		Motor yachts
		Sail boats
Tankers	Bulk carriage of liquids or compressed gas	Row boats
		Oil, natural gas, and chemical tankers
Tug/barge	Tug: Designed for towing or pushing	Resupply vessels
	Barge: nonpropelled vessel for carriage of bulk or mixed cargo	Bulk cargo transporter

Source: Pizzolato et al. 2014.

Methodology

Study area

The study area for this research is the Northern Canada Vessel Traffic Services (NORDREG) Zone. Figure 1 shows the NORDREG zone in grey. This area encompasses Canadian Arctic waters, including major shipping routes; the Arctic Bridge through Hudson Strait and Hudson Bay; and the

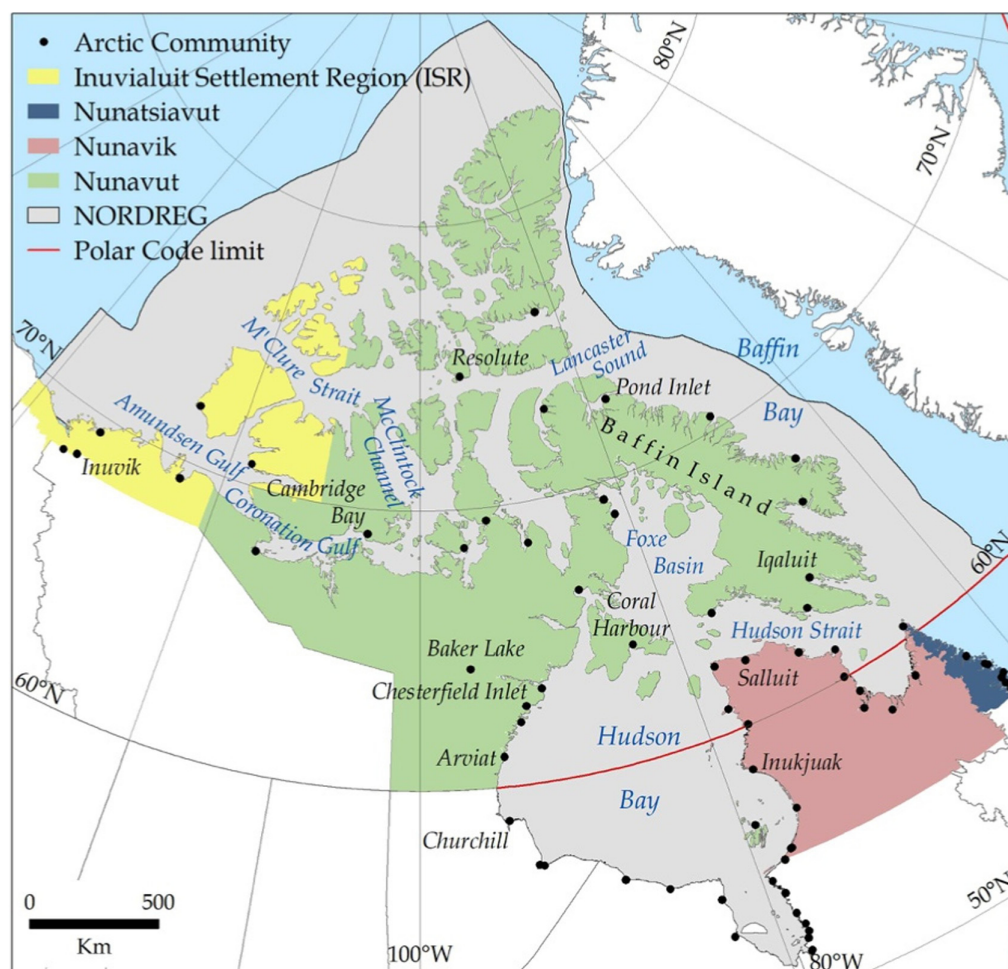


Fig. 1. Canadian Arctic and NORDREG Zone. This figure was created using ESRI ArcMap version 10.7 and assembled from the following data sources (shapefiles): Arctic Communities: [Natural Resources Canada \(2019\)](#) Canadian Geographical Names GeoBase Series. Online: open.canada.ca/data/en/dataset/e27c6eba-3c5d-4051-9db2-082dc6411c2c. NORDREG Zone: [Canadian Coastguard \(2013\)](#) Vessel Traffic Reporting Arctic Canada Traffic Zone (NORDREG). Online: cgc-gcc.gc.ca/index-eng.html. Inuit Regions: Crown-Indigenous Relations and Northern Affairs Canada, Government of Canada Open Government License. Online: open.canada.ca/data/en/dataset/f242b881-75e3-40bb-a148-63410b4ce2af#wb-auto-6. Polar Code: International Maritime Organization (IMO) Polar Code document. Online: imo.org/en/MediaCentre/HotTopics/polar/Documents/POLAR%20CODE%20TEXT%20AS%20ADOPTED.pdf. Arctic Council (2009).

Northwest Passages through the Canadian Arctic Archipelago (**Fig. 1**). The NORDREG zone is the region in the Canadian Arctic where vessels report their position and vessel information. It is important to note here that the IMO definition of the Arctic (which would be affected by the potential HFO ban) varies slightly from the NORDREG zone. The Polar Code definition of the Arctic that the IMO uses only applies to ships travelling north of 60°. **Figure 1** shows that this would exclude parts of the Hudson Bay that are located south of 60°. For this paper, we have utilized NORDREG data that include some shipping south of 60°. We recognize that this might alter the findings in terms of exact HFO usage in the Polar Code definition of the Arctic; however, it provides more detailed information for Canadian specific purposes, as NORDREG is regularly utilized by relevant federal departments including Transport Canada and the Canadian Coast Guard.

Shipping database

The shipping database used in this study was constructed using Canadian Coast Guard nonspatial NORDREG ship archive data (2010–2018) that was extensively quality controlled for accuracy and consistency (see Pizzolato et al. 2014). The NORDREG data set contains daily reports of vessel locations at 16:00 UTC for mandatory reporting vessels since 2010 (i.e., vessels that are >300 gross tonnes, engaged in towing or pushing another vessel if the combined tonnage is >500 gross tonnes, if a vessel is carrying a pollutant or dangerous good, or towing a vessel carrying a pollutant or dangerous good (CCG 2013)) as well as vessel positions that voluntarily reported their location with the NORDREG zone. The NORDREG data also include an archive with vessel name, call sign, IMO number, entry and exit dates of the NORDREG zone, vessel length, width, and other nonspatial characteristics. Between 2010 and 2018, there were 601 unique vessels operating in the NORDREG zone. An analysis of fuel type usage was conducted based on these 601 unique vessels.

Fuel type category

For the purpose of this paper, we examined all fuel types that fall under the broader definition of HFO (including IFO) as described by Det Norske Veritas (2011) (see Det Norske Veritas 2011 for a detailed account of different marine fuels). Determination of fuel types for this study were made using a variety of different methods. Identification of fuel use among ships is challenging as there are no publicly available and reliable databases that readily contain this information—although some pay per use databases are available based on our assessment, even those are incomplete. Our goal was to determine the fuel type, as either distillate or residual, for each of the 601 vessels that operated in the Canadian Arctic NORDREG zone between 2010 and 2018. Residual fuel is fuel that contains a majority of HFO, and distillate fuel is fuel that contains a majority of diesel or gas oil. It is residual (HFO) fuel that is proposed to be banned in the Arctic. There are other propulsion methods used, for example, LNG, but none of the ships in our data set were found to be using these propulsion methods. There are also sailing vessels that may not have used any fuel during their transit of the Canadian Arctic. We determined that their fuel use would have been distillate if they had a motor onboard; however, they may not have used this fuel at that time. Fuel type was determined using the following steps (Fig. 2).

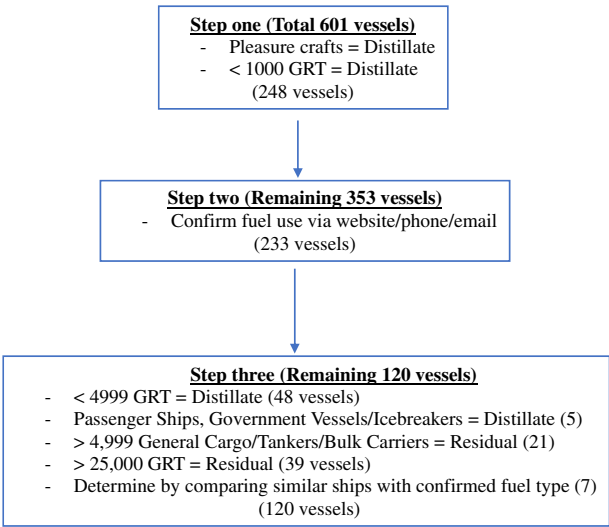


Fig. 2. Fuel data collection.

Step one—removing vessels most likely using distillate fuel (and not HFO)

We identified vessels that could be confidently assessed to be using distillate fuel. For example, all pleasure crafts were estimated to be using distillate fuel. Most of these ships were sailing vessels and yachts. It is highly unlikely that sailing vessels and yachts use residual fuel. In addition, all vessels under 1000 gross register tonnage (GRT) were determined to be using distillate fuel. [Det Norske Veritas \(2011\)](#) found that none of the 290 vessels under 1000 GRT in their study used residual fuel. There were 111 vessels that did not have a confirmed GRT, most of these vessels were pleasure crafts. We estimated their GRT by comparing the length, breadth, and vessel type with vessels that had a known GRT. Most of these vessels were under 1000 GRT, thus they were estimated to be using distillate fuel as well. We estimated fuel type for 248 vessels using this method.

Step two—confirming fuel type for remaining vessels

For the remaining 353 vessels, we determined fuel type by obtaining information directly from ship owners or operators for each vessel. This was done by checking online databases linked to IMO/MMSI (maritime mobile service identity) numbers. The online databases used included: [marinetraffic.com](#), [Fleetmon.com](#), Canadian vessel registration system ([wwwapps.tc.gc.ca/Saf-Sec-Sur/4/vrqs-srib/eng/vessel-registrations](#)), and Russian Maritime Registry ([rs-class.org/en/](#)). If these were not successful in finding owner–operator information, these details were accessed via a Google search. Once owners–operators were determined, the Google search engine was used to find their corresponding websites and contact details. Some websites contained detailed information about the vessels. This was examined for fuel type information. If fuel type information was available and clear this was used as confirmed fuel type for the vessel in question. If fuel type could not be determined, owners or operators were contacted via email and (or) phone to ask for this information. This system was successful for confirmed fuel type use for 233 of the vessels, which is approximately 40% of the vessels within the data set.

Step three—estimating fuel type for remaining vessels

For the 119 vessels that remained unclassified we estimated fuel type using the following methods. First, we evaluated the data obtained by the [Det Norske Veritas \(2011\)](#) report and it was determined that vessels under 4999 GRT would most likely use distillate fuel. They found that of the 739 vessels under 4999 GRT <3% of vessels were using residual fuel. Thus, for vessels under 4999 GRT in our data set (that we did not already have confirmed fuel type for), we estimated that they were using distillate fuel (48).

Similarly, the [Det Norske Veritas \(2011\)](#) reported that all vessels weighing more than 25 000 GRT used HFO in the Arctic. Thus, for vessels over 25 000 GRT that we did not have fuel information for we determined that these vessels would most likely be operating off of residual fuel (passenger ships were an exception to this rule as all passenger ships that we contacted identified that they used distillate fuel in the Canadian Arctic; therefore, we determined that all passenger ships regardless of size would most likely be using distillate fuel). Thirty-nine vessels were estimated in this way. Of the 171 vessels falling between 4999 and 25 000 GRT, there were 32 vessels where we did not have confirmed fuel type data. For these vessels, we estimated fuel type based on various factors. Firstly, we compared these vessels with others that had fuel type confirmed. If we could confirm that vessel type, use, and owner–operator were the same we determined that these vessels would most likely be using the same fuel as those we had already confirmed (seven ships were estimated in this way). Secondly, vessel type: All government vessels–icebreakers and passenger ships of this size were determined to be using distillate fuel (five vessels were determined this way). Finally, general cargo, tankers, and bulk carriers were estimated to be using residual fuel based on our other findings (21 vessels were estimated in this way).

We were able to confirm fuel use for 233 marine vessels out of 601. Perhaps more significantly, we were able to confirm fuel use for 70% of marine vessels identified as HFO users, which was the focus of our investigation.

Limitations

While direct confirmation of fuel use via email, phone, or website is the most accurate portrayal of actual fuel use that we used in this data set, it is important to note that there were some occasions where we were provided with conflicting information from a company–organization representative on the phone compared with what we had from other reputable sources. In these instances, we went with the fuel source that we deemed most likely to be accurate based on the information we had available. In addition, much of the information we have is current and up to date for 2019. It was not as easy to obtain information about what vessels would have been using at the time they were transiting through the Canadian Arctic (for some, potentially 9 years ago). We chose to go with current fuel use, as few vessels would have changed the type of fuel they used and as a result we believe this still accurately reflects general fuel use over the past 9 years. It is possible (and even likely) that some passenger ships have changed their fuel use from HFO to distillate in recent years. In addition, our findings for tugs and barges may also underestimate residual fuel use, because of their size they were automatically estimated to be using distillate fuel (if we could not confirm fuel use). The information we were able to obtain represents a best estimate of available information at the time of analysis.

Results

The results of our study show that approximately 37% of all unique vessels travelling through the Canadian Arctic between 2010 and 2018 most likely used HFO. [Tables 2 and 3](#) break down the findings further by size and by ship type, respectively. The findings show that vessels over 5000 GRT made up the vast majority of HFO use; this finding is similar to [Comer et al. \(2016\)](#) and [Det Norske Veritas \(2011\)](#). [Table 3](#) also shows that bulk carriers, general cargo, and tanker ships made up nearly all of the confirmed and estimated HFO use. This finding was expected and supports previous findings ([Det Norske Veritas 2011](#); [Comer et al. 2016](#)).

By combining our nonspatial database with our spatial database, we can see a more complete picture of HFO use each year and in which geographic areas of the Canadian Arctic HFO use is more

Table 2. Fuel use by vessel size.

Vessel size (GRT)	Number of vessels	Distillate confirmed (estimated)	Residual confirmed (residual estimated)	Confirmed HFO use, % (estimated use, %)
<100	127	4 (123)	0 (0)	0
100–299	60	1 (59)	0 (0)	0
300–499	43	2 (41)	0 (0)	0
500–999	39	14 (25)	0 (0)	0
1000–4999	79	26 (49)	4 (0)	4 (8) 13%
5000–24 999	172	28 (5)	112 (27)	65 (16) 81%
25 000–49 999	79	2 (0)	39 (38)	49 (48) 97%
>50 000	2	1 (1)	0 (0)	0
Total	601	78 (303) 381	155 (65) 220	26 (11) 37%

Note: Bold text represents total values.

Table 3. Fuel use by vessel type.

Vessel type	Number of vessels	Distillate confirmed (distillate estimated)	Residual confirmed (residual estimated)	Heavy fuel oil use, %
Bulk carriers	132	0 (0)	89 (43)	100
Fishing vessels	53	3 (50)	0 (0)	0
General cargo	44	0 (1)	40 (3)	97.7
Government vessels or icebreakers	79	37 (42)	0 (0)	0
Gas exploration	2	1 (1)	0 (0)	0
Passenger ships	28	21 (7)	0 (0)	0
Pleasure crafts	164	6 (158)	0 (0)	0
Tanker Ships	45	0 (1)	25 (19)	97.7
Tug or barge	54	10 (43)	1 (0)	1.9
Total	601	381	220	37

Table 4. Ship count and kilometres travelled by year.

		2010	2011	2012	2013	2014	2015	2016	2017	2018
All ships (distillate and residual)	Unique ship count	131	123	125	130	136	127	125	166	148
	Distance travelled (km)	844 171	803 431	736 569	790 701	919 729	885 282	911 617	1 129 734	1 054 809
Residual ships	Unique ship count (%)	50 (38)	41 (33)	39 (31)	41 (32)	47 (35)	44 (35)	43 (34)	56 (34)	63 (43)
	Distance travelled, km (%)	353 424 (42)	339 598 (42)	331 798 (45)	372 541 (47)	430 591 (47)	403 664 (46)	356 819 (39)	527 715 (47)	534 305 (51)

prevalent. **Table 4** shows ship count and distance travelled for all ships (distillate and residual), residual-HFO ships, and residual-HFO ship percentages. **Table 3** shows there were 601 unique vessels travelling through the Canadian Arctic between 2010 and 2018. **Table 4** breaks the ship count down by year, which is shown in **Figs. 3** and **4**. We can see that the number of ships using HFO coming through the Canadian Arctic remains relatively stable until 2016, when we start to see a slight increase (**Fig. 3**). When examining the total kilometres travelled by ships using HFO, we see that distance travelled has increased slightly since 2010 with a decrease in 2016 (**Fig. 4**). Each year the percentage of ships using HFO were relatively consistent until 2018, the same can be said for unique ship count percentage. There are a few points of interest that this analysis demonstrates. Ships using HFO represent 37% of the overall unique ships between 2010 and 2018 (as shown in **Table 3**). However, on average, ships using HFO travel further in the Canadian Arctic than ships using distillates. Ships using HFO represent approximately 45% of the total distance travelled between 2010 and 2018 and, in 2018, these ships accounted for over 50% of the total distance travelled among all ships.

Our spatial analysis shows where ships using HFO were travelling between 2011 and 2018 and how this has changed over time. **Figure 5** shows that ships using HFO travel throughout the Canadian Arctic; however, the map clearly shows that there are some areas that experience higher

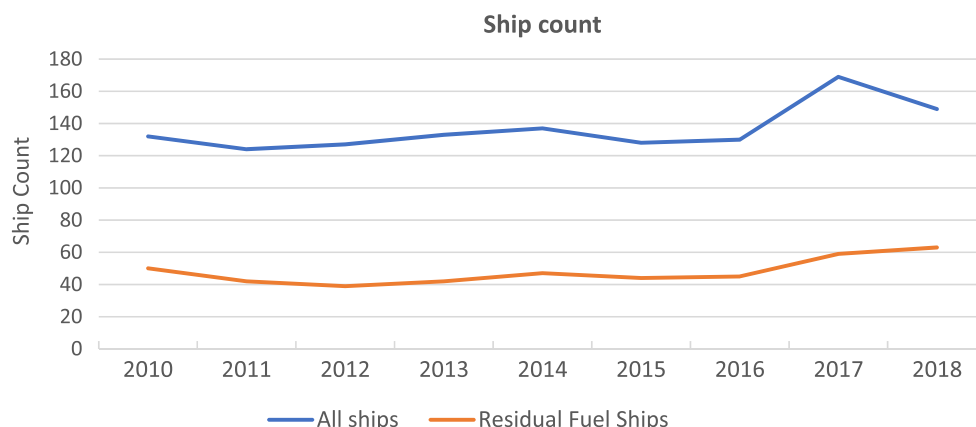


Fig. 3. Number of unique ships (all and residual) travelling through the Canadian Arctic each year from 2010 to 2018.

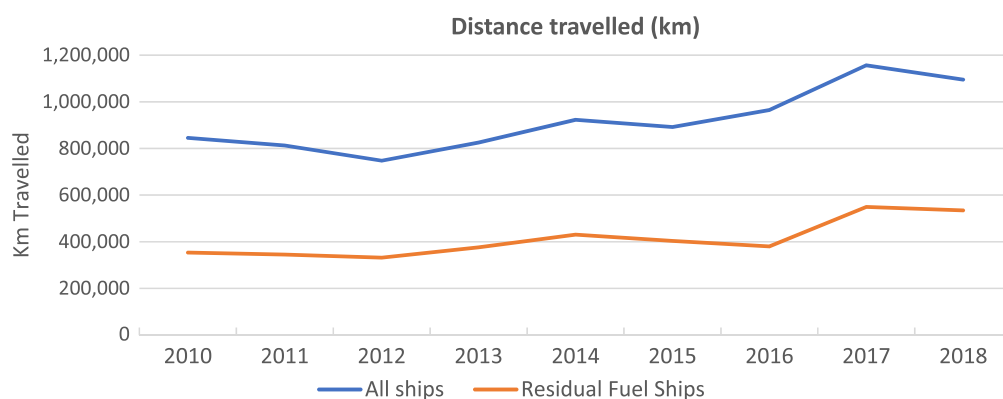


Fig. 4. Distance travelled by all and residual ships each year from 2010 to 2018.

concentrations of ships using HFO, specifically along the Hudson Strait and Eclipse Sound near Pond Inlet, Nunavut, into the Baffin Bay area. [Figure 5](#) also shows that the number of ships using HFO fuel has increased over time; however, the areas of concentration have remained relatively consistent.

The vast majority of HFO use between 2010 and 2018 in the Canadian Arctic has occurred among three general ship types (there was one tug-barge that was confirmed to be using residual fuel that did not fall into one of these three categories): general cargo, bulk carriers, and tanker ships. General cargo are resupply ships that transport supplies to Arctic communities. Bulk carriers are ships that are designed to carry bulk cargo such as grain, timber, and ore. Pre-2016, the majority of these bulk carrier vessels were used to transport grain from Port of Churchill across the globe, from 2016 onwards they have generally been used to service mines. Tanker ships transport liquids or gases, generally oil or chemicals, and tankers provide fuel and other liquids to communities, mines, and other locations throughout the Canadian Arctic ([Dawson et al. 2018](#)). [Figures 6](#) and [7](#) break down residual use into these three categories, which helps to show the changes over time among these three groups, and how and in what context HFO is being used by marine vessels in the Canadian Arctic. On average, between 2010 and 2018 unique general cargo vessels make up 28% of estimated HFO users each year, unique bulk carriers make up approximately 48% of HFO users each year, and tanker ships

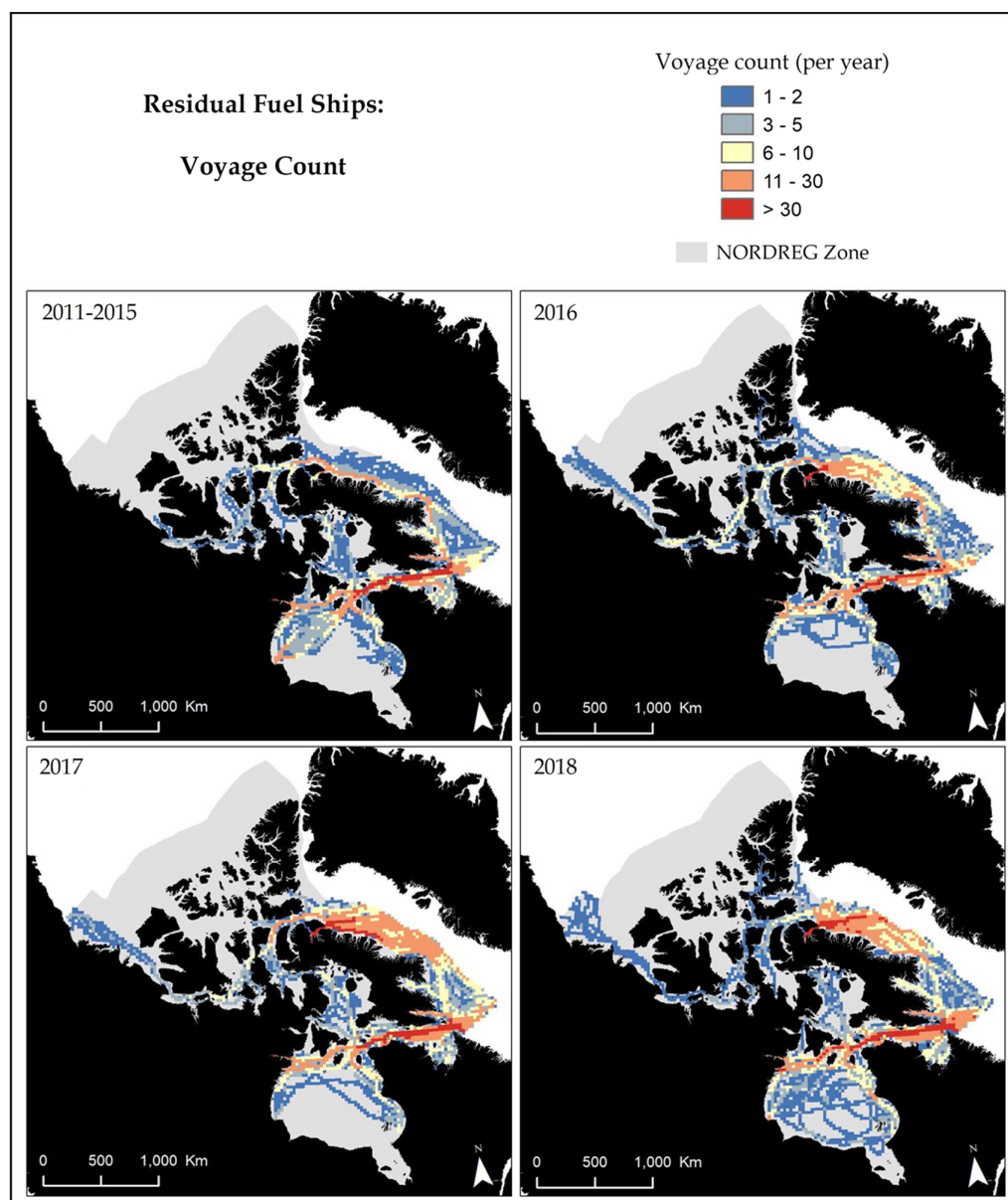


Fig. 5. Trends in residual and heavy fuel oil shipping activity based on voyage count within the Northern Canada Vessel Traffic Services Zone 2011–2018. This figure was created using ESRI ArcMap version 10.7 and assembled from the following data sources (shapefiles): NORDREG Zone and shipping data: [Canadian Coastguard \(2013\)](https://cgc-gcc.gc.ca/index-eng.html) Vessel Traffic Reporting Arctic Canada Traffic Zone (NORDREG). Online: cgc-gcc.gc.ca/index-eng.html. Land shapefile: [Natural Resources Canada \(2019\)](https://open.canada.ca/en/open-government-licence-canada). Contains information licensed under the Open Government Licence – Canada. Online: open.canada.ca/en/open-government-licence-canada. [Arctic Council \(2009\)](https://arctic-council.org/).

make up approximately 24% of HFO users each year. In terms of kilometres travelled, on average general cargo vessels travel the furthest distance each year, making up 47% of the kilometres travelled by these three HFO-fueled vessel categories, tanker ships make up 29% of the kilometres travelled per year, and bulk carriers make up 24% of the kilometres travelled per year.

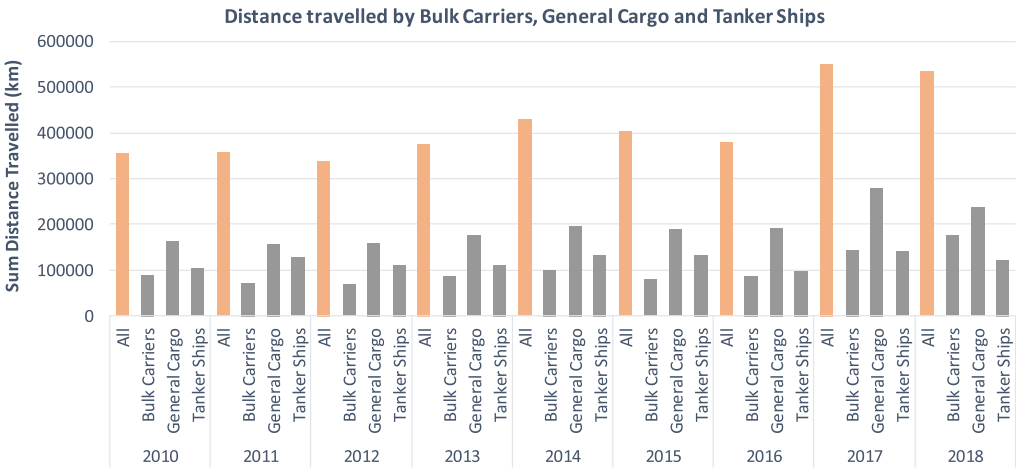


Fig. 6. Trends in residual fuel use in terms of distance travelled (kilometres) broken down by ship type from 2010 to 2018.

Bulk carriers

The number of unique bulk carrier vessels has remained fairly stable each year from 2010 until we began to see an increase from 2016 (Fig. 7). When viewing the spatial distribution (Fig. 8), we can see that between 2011 and 2015 the majority of bulk carriers were travelling to and from the Port of Churchill. These bulk carriers were transporting grain from Canada to global markets. The Port of Churchill, Manitoba, closed in August 2016, which is why so few bulk carriers were seen in this area until the Port of Churchill reopened and its first grain vessel left the Port in September 2019 (Franz-Warkentin 2019). The figures from 2016 onwards show that despite the Port of Churchill closing, the number of bulk carriers increased. Figure 8 shows that this increase is directly linked to the increase in bulk carriers travelling to and from Milne Inlet near Pond Inlet, Nunavut, community (most likely caused by traffic related to the Mary River Mine located on Baffin Island), and traffic travelling to and from Deception Bay near Salluit, Quebec (most likely caused by traffic related to Raglan and Nunavik Nickel mines using the port in Deception Bay,

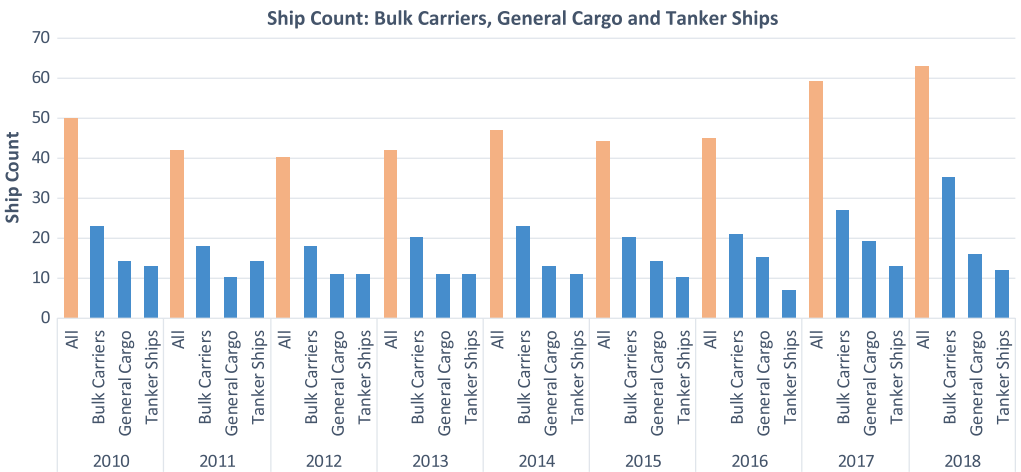


Fig. 7. Trends in residual fuel use in terms of unique ship count broken down by ship type from 2010 to 2018.

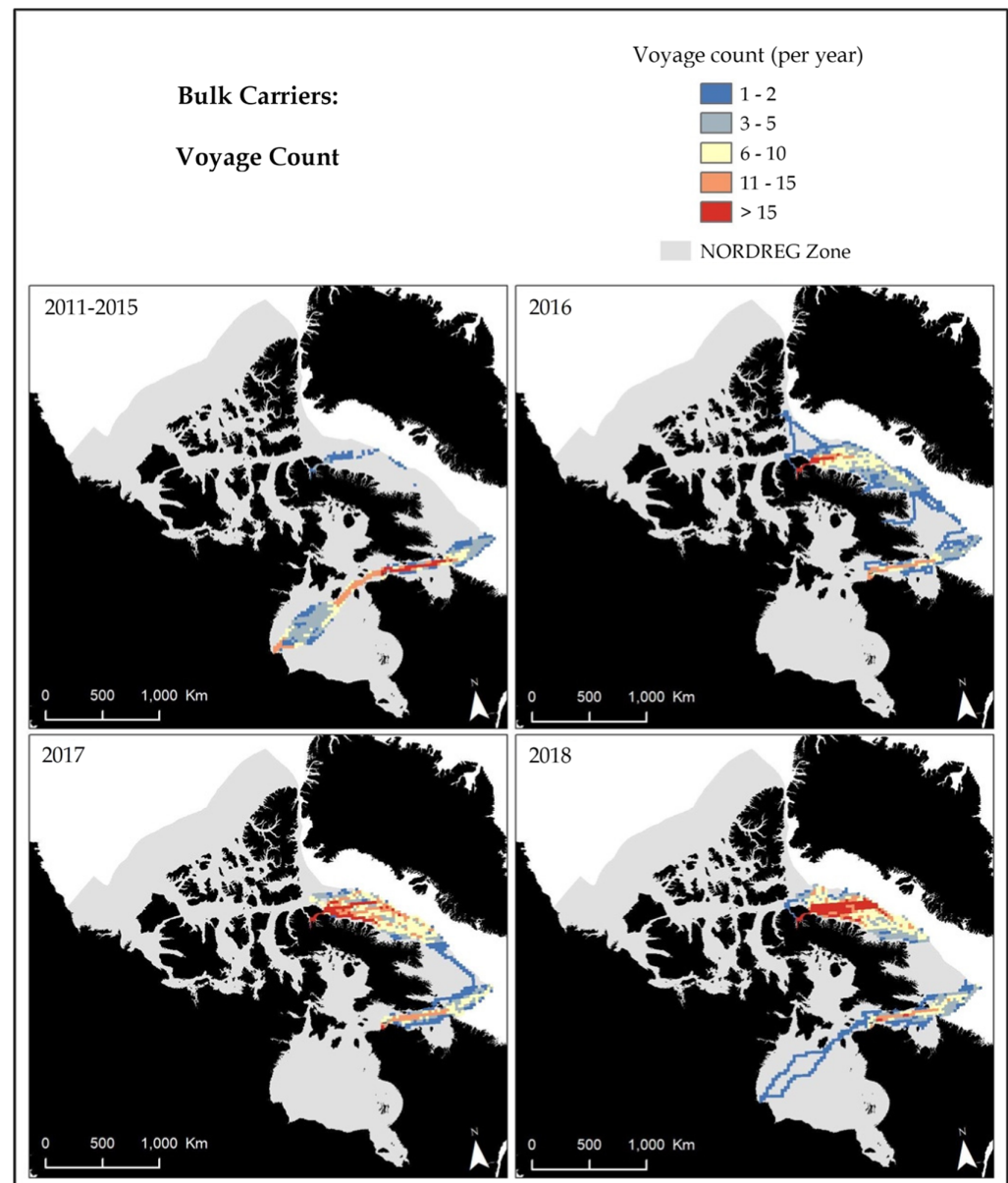


Fig. 8. Trends of bulk carrier shipping activity from 2011 to 2018. This figure was created using ESRI ArcMap version 10.7 and assembled from the following data sources (shapefiles): NORDREG Zone and shipping data: [Canadian Coastguard \(2013\)](https://www.ccg.gc.ca/index-eng.html) Vessel Traffic Reporting Arctic Canada Traffic Zone (NORDREG). Online: [ccg-gcc.gc.ca/index-eng.html](https://www.ccg.gc.ca/index-eng.html). Land shapefile:

General cargo

Figures 6 and **7** show that general cargo vessels have fewer unique ships travelling through the Canadian Arctic each year compared with bulk carriers. General cargo vessels overall travel the furthest distance compared with bulk carriers and tanker ships. The number of kilometres travelled by general cargo ships has steadily increased since 2010, whereas the number of unique general cargo vessels coming through each year has remained relatively stable. The spatial figures (**Fig. 9**) show that general cargo vessels travel vast distances throughout the Canadian Arctic stopping at different Arctic communities, with the Hudson Strait and northern section of Hudson Bay experiencing the highest intensity of this traffic. Many Arctic communities are only accessible by air or sea and therefore rely on general cargo and tanker ships for their annual resupply. The two main resupply operators in the Canadian Arctic are Desgagnes Transarctik and NEAS (**FedNav 2017**). Between 2010 and 2018 the average number of unique general cargo vessels travelling through the Canadian Arctic each year was 14. This is an important point that we will return to in the discussion section. **Figures 9** and **10** also show significant traffic through to Rankin Inlet, Baker Lake, and Chesterfield Inlet, Nunavut, for both cargo and tanker ships, which is likely linked to servicing of the Meadowbank Gold Mine and Meliadine Mine located near Baker Lake and Rankin Inlet, respectively (**Dawson et al. 2018**; **Babb et al. 2019**), as well as the recently opened Amaruk mine near Baker Lake.

Tanker ships

The number of unique tanker ships and the distance travelled by tanker ships each year has remained relatively stable between 2010 and 2018. **Fig. 10** shows that similar to general cargo vessels, tanker ships travel to many different areas across the Canadian Arctic reflecting their annual resupply routes (**Dawson et al. 2018**), with north of Hudson Bay and Hudson Strait again being the points experiencing the highest voyage numbers. Unlike general cargo vessels and bulk carriers, the number of unique tanker ships and distance travelled by tanker ships has not significantly increased between 2010 and 2018 (**Figs. 6** and **7**).

Discussion

The study provides a detailed account of HFO use by marine vessels in the Canadian Arctic between 2010 and 2018. The results show that approximately 37% of unique vessels travelling through the Canadian Arctic between 2010 and 2018 were fueled by HFO. In addition, HFO-fueled ships make up approximately 45% of the total distance (kilometres) travelled by all vessels between 2010 and 2018. By 2018, HFO-fueled ships made up nearly 50% of the total distance travelled by all ships in that year. In the Canadian Arctic, we can determine that the vast majority of HFO use is made up of just three different ship categories: bulk carriers, general cargo, and tanker ships. These ship types all operate in different ways and in different areas, which should be considered for potential future HFO ban policies.

The findings show that general cargo travel the furthest distances in relation to other HFO users; however, the number of general cargo vessels is still relatively low. Approximately 14 general cargo vessels travel through the Canadian Arctic each year. This means that switching to distillate fuel could have a relatively higher economic impact on each cargo vessel because of their long-distance travel; however, the cost of making the switch to using distillate fuel, such as modifying engines, could be relatively cheaper overall and have a higher environmental impact because of the low number of vessels relative to the distance travelled. Similar to cargo vessels, tanker ships also have a relatively low number of vessels in relation to the distance travelled. Twelve tanker ships travelled through the Canadian Arctic in 2018. Switching even a small number of general cargo and tanker ships to using distillate fuel could have a large impact on decreasing overall HFO use. Arctic communities rely on general cargo and tanker ships to provide annual sealift (resupply). Resupply shipping companies have confirmed

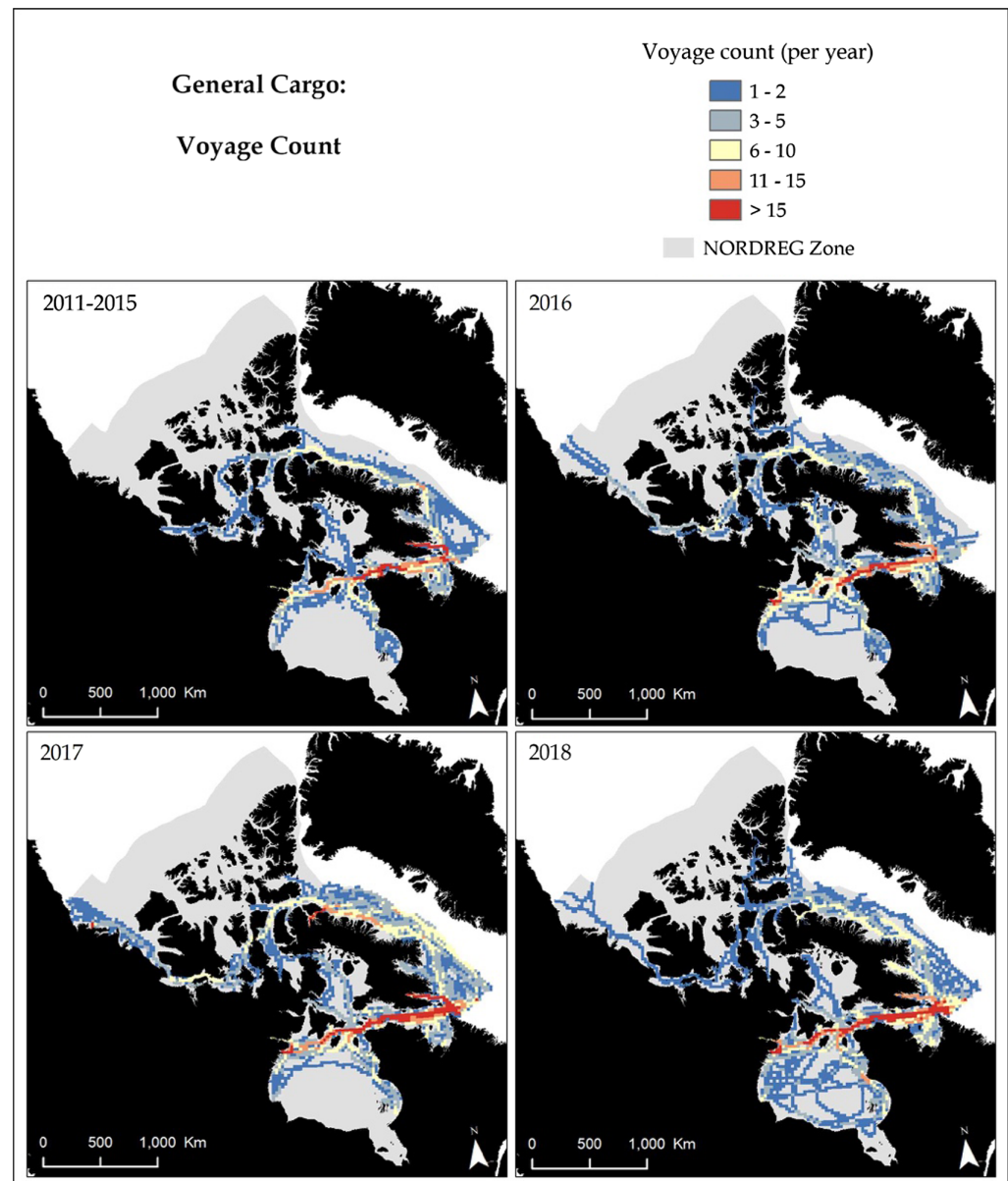


Fig. 9. Trends of general cargo shipping activity from 2011 to 2018. This figure was created using ESRI ArcMap version 10.7 and assembled from the following data sources (shapefiles): NORDREG Zone and shipping data: [Canadian Coastguard \(2013\) Vessel Traffic Reporting Arctic Canada Traffic Zone \(NORDREG\)](https://www.ccg-gcc.gc.ca/index-eng.html). Online: [ccg-gcc.gc.ca/index-eng.html](https://www.ccg-gcc.gc.ca/index-eng.html). Land shapefile: [Natural Resources Canada \(2019\)](https://www.nrc.ca/eng/open-government-licence-canada). Contains information licensed under the Open Government Licence – Canada. Online: [open.canada.ca/en/open-government-licence-canada](https://www.open.canada.ca/en/open-government-licence-canada). Arctic Council (2009).

that the increased cost of switching fuel will not be able to be absorbed by the companies and will have to be passed onto communities within the total cost of the goods (George 2017), which could have profound economic impacts for shipping companies and communities. Both the Canadian Government and Inuit organizations have raised concerns about this issue. Canadian Arctic communities are already experiencing prohibitive food and supply prices, and if costs increased this could

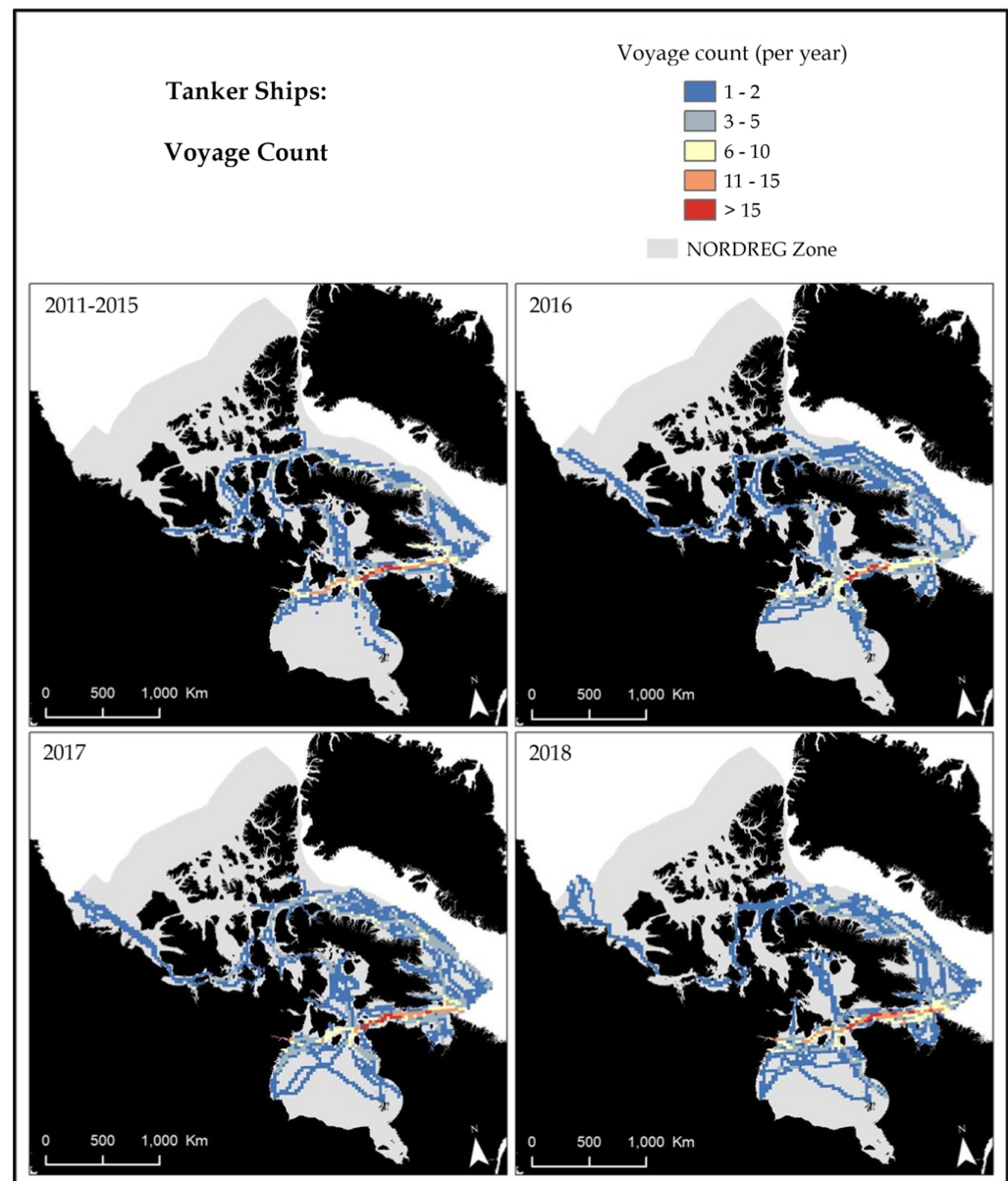


Fig. 10. Trends in tanker ships shipping activity from 2011 to 2018. This figure was created using ESRI ArcMap version 10.7 and assembled from the following data sources (shapefiles): NORDREG Zone and shipping data: [Canadian Coastguard \(2013\) Vessel Traffic Reporting Arctic Canada Traffic Zone \(NORDREG\)](https://cgc-gcc.gc.ca/index-eng.html). Online: cgc-gcc.gc.ca/index-eng.html. Land shapefile: [Natural Resources Canada \(2019\)](https://open.canada.ca/en/open-government-licence-canada). Contains information licensed under the Open Government Licence – Canada. Online: open.canada.ca/en/open-government-licence-canada. Arctic Council (2009).

contribute to issues around food security ([Wesche and Chan 2010](#); [Cunsolo Willox et al. 2012](#)). It is imperative that these potential impacts be considered in discussing the proposed HFO ban.

The results show that bulk carriers travel relatively shorter distances in the Canadian Arctic compared with general cargo vessels; however, there are a higher number of them. In 2018, there were 32 unique

bulk carriers travelling through the Canadian Arctic. In addition, it is expected that the number of bulk carriers in the Canadian Arctic will continue to rapidly increase as a result of increased mining interests up north. Baffinland, which owns Mary River Mine, and already uses a high number of the bulk carriers in the Canadian Arctic is currently seeking approval for a phase 2 expansion of the mine, which will see them producing double the amount of ore each year (Frizzell 2019). This will significantly increase vessel counts and distance travelled if it goes ahead. There are also several other proposed mining projects that would rely on marine transport in the Canadian Arctic (Babb et al. 2019). Currently, the Government of Canada has committed funding for the Grays Bay Road and Port project, which aims to construct a 227 km all-weather road connecting to a deep-sea port at Grays Bay in Coronation Gulf located in the western area of Nunavut (George 2019b). This road aims to make it more economically viable for mining to occur in these remote areas. The focus of the potential impacts of HFO fuel ban has been on the potential impact that will exist for Canadian Arctic communities. However, our findings show that bulk carriers utilized by mining companies also play a significant role in Canadian Arctic HFO use, and their role is only expected to increase in the years to come. The findings also show that mining companies are contributing to the increase of general cargo and tanker ships in the Canadian Arctic as they use these vessel types to provide supplies and fuel to mines.

In addition, the maps demonstrate that the majority of HFO usage occurs along the Hudson Strait, the north area of Hudson Bay, and Eclipse Sound near Pond Inlet into the Baffin Bay area. This finding is particularly significant as the extensive HFO usage near Pond Inlet occurs in the newly created Tallurutiup Imanga National Marine Conservation Area (NMCA) in Nunavut, which was announced in August 2019. This area has been described as “a large natural and cultural seascape that is one of the most significant ecological areas in the world” (Parks Canada 2019, para. 1). This area is an important habitat for polar bears, bowhead whale, narwhal, and beluga whale, as well as an important cultural area for local Inuit. Marine conservation areas are created to protect and sustain important ecological environments and HFO-use in this area could pose significant threats to the ecological environment in terms of the negative impacts of air and water pollution and potential oil spills. The Tallurutiup Imanga agreement does not currently include regulations related to shipping (see IIBA-TINMCA 2019, Article 10, p. 43); however, the agreement does state that the Board (selected to monitor the NMCA) is responsible for the “development of recommendations to responsible authorities, with respect to marine shipping activities within the Tallurutiup Imanga NMCA” (IIBA-TINMCA 2019, p. 27). This area is used most heavily by the bulk carriers travelling to and from the Mary River mine using Milne Inlet near Pond Inlet to load mined iron ore. Phasing out the use of HFO in mining-related shipping could decrease HFO-use in the Canadian Arctic significantly.

Although the current focus of a potential HFO-ban is for ships to switch to lighter distillate fuels—as this is the easiest and cheapest alternative for most ships—there are other proposed methods of propulsion (see Det Norske Veritas 2019 for further information on fuel alternatives for marine vessels). LNG is described by Det Norske Veritas (2019) as a potential alternative; however, there will be costs involved in switching to LNG, including installing LNG machinery and fuel tanks and training of crew. There is also currently a lack of LNG infrastructure in the Arctic, which could present increased difficulties for LNG uptake. In addition, even though when compared with distillate and residual fuels, it has been argued that LNG presents a more environmentally friendly option, the fuel still contributes to greenhouse gas (GHG) emissions, and recently researchers have found that LNG usage in international shipping may produce more GHGs than previously thought (Pavlenko et al. 2020). In addition, some researchers have also found that very low sulphur fuel oil—recently popularized after the implementation of the 0.5% sulphur cap on fuel in January 2020—may emit higher black carbon emissions than high sulphur fuel oils (IMO PPR 7/8 2019). Thus, there is a pressing need to seek out other carbon-friendly fuels and (or) innovation into reducing the pollutants emitted by current fuels.

that could be viable in the years to come. This includes additional investments into oil spill response in the Canadian Arctic to minimize the negative impacts of a spill should one occur. A ban of HFO use and carriage for use in the Arctic is most likely only the beginning of measures to be put in place to limit the environmental impacts of marine vessels in the future. [Det Norske Veritas \(2019\)](#) explains that “it will no longer be possible to assume a ‘stationary’ regulatory and technology landscape for the lifetime of a ship” ([Det Norske Veritas 2019](#), p. 49). These are factors that need to be considered in the development of new ships as old ships reach their lifespan and require renewal.

We have compiled data that represent the best estimate of fuel use in the Canadian Arctic thus far; however, it would be valuable to have fuel type usage and carriage data be part of the requirement for reporting by ships that enter Canadian waters. This could provide a more accurate and up to date data set and would provide additional information such as the amount of fuel that ships are carrying in addition to what type of fuel they are using. Availability of this data is invaluable for research and may provide some insight for decision-makers in the creation of fuel use policies and in the continued monitoring of environmental impacts of Arctic shipping. While the discussions around banning HFO use by ships in the Arctic present various challenges—that all deserve consideration—it is important that we continue to work to seek ways to limit our environmental impacts while also considering the importance of economic development and the economic, social, and cultural consequences of all proposed policies.

Author contributions

NVL, JD, and AC conceived and designed the study. NVL and AC performed the experiments/collected the data. NVL, JD, and AC analyzed and interpreted the data. NVL, JD, and AC contributed resources. NVL, JD, and AC drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

References

- AECO. 2019. Expedition cruise industry charts course for sustainable Arctic tourism. AECO, Tromsø, Norway [online]: Available from aeco.no/2019/11/expedition-cruise-industry-charts-course-for-sustainable-arctic-tourism/.
- AMAP. 2017. Adaptation actions for a changing Arctic: perspectives from the barents area. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
- AMSA. 2009. Arctic marine shipping assessment [online]: Available from pame.is/images/03_Projects/AMSA/AMSA_2009_report/AMSA_2009_Report_2nd_print.pdf.
- Arctic Council. April 2009. Arctic marine shipping assessment report.
- Babb DG, Andrews J, Dawson J, Landry D, Mussells O, and Weber M. 2019. Transportation and community use of the marine environment. *In* From science to policy in the Greater Hudson Bay marine region: an integrated regional impact study (IRIS) of climate change and modernization. *Edited by* Z Kuzyk and L Candlish. ArcticNet, Quebec City, Quebec [online]: Available from arcticnet.ulaval.ca/docs/IRIS3-HudsonBay-VF.pdf.

Browning L, Hartley S, Bandemehr A, Gathright K, and Miller W. 2012. Demonstration of fuel switching on oceangoing vessels in the Gulf of Mexico. *Journal of the Air & Waste Management Association*, 62(9): 1093–1101. PMID: [23019823](#) DOI: [10.1080/10962247.2012.697974](#)

Canadian Coastguard (CCG). 2013. Vessel traffic reporting Arctic Canada Traffic Zone (NORDREG) [online]: Available from [ccg-gcc.gc.ca/index-eng.html](#).

Comer B, Olmer N, and Mao X. 2016. Heavy fuel use in Arctic shipping in 2015. Working Paper. The International Council on Clean Transportation, Washington, DC, USA [online]: Available from [theicct.org/sites/default/files/publications/HFO%20Arctic%20Shipping_working-paper_vF_21102016.pdf](#).

Corbett JJ, and Winebrake JJ. 2008. Emissions tradeoffs among alternative marine fuels: total fuel cycle analysis of residual oil, marine gas oil, and marine diesel oil. *Journal of the Air & Waste Management Association*, 58(4): 538–542. PMID: [18422040](#) DOI: [10.3155/1047-3289.58.4.538](#)

Cunsolo Willox A, Harper SL, Ford JD, Landman K, Houle K, and Edge VL. 2012. “From this place and of this place:” climate change, sense of place, and health in Nunatsiavut, Canada. *Social Science & Medicine*, 75(3): 538–547. PMID: [22595069](#) DOI: [10.1016/j.socscimed.2012.03.043](#)

Dawson J, Pizzolato L, Howell SEL, Copland L, and Johnston ME. 2018. Temporal and spatial patterns of ship traffic in the Canadian Arctic from 1990 to 2015. *Arctic*, 71(1): 15–26. DOI: [10.14430/arctic4698](#)

DeCola E, and Robertson T. 2018. Phasing out the use and carriage for us of heavy fuel oil in the Canadian Arctic: impacts to Northern communities. Report to WWF-Canada [online]: Available from [assets.wwf.ca/downloads/phasing_out_heavy_fuel_oil_report.pdf](#).

Det Norske Veritas. 2011. Heavy fuel in the Arctic (Phase 1). Report for PAME [online]: Available from [pame.is/images/03_Projects/HFO/HFO_in_the_Arctic_Phase_I.pdf](#).

Det Norske Veritas. 2013. HFO in the Arctic—phase 2. Report for PAME [online]: Available from [pame.is/images/03_Projects/AMSA/Heavy_Fuel_in_the_Arctic/HFO%20in%20the%20Arctic%20Phase%20II%20final%20report%20by%20DNV_signed.pdf](#).

Det Norske Veritas. 2019. Alternative fuels in the Arctic. Report to PAME [online]: Available from [pame.is/index.php/document-library/pame-reports-new/pame-ministerial-deliverables/2019-11th-arctic-council-ministerial-meeting-rovaniemi-finland/428-report-on-the-environmental-economic-technical-and-practical-aspects-of-the-use-by-ships-in-the-arctic-of-alternative-fuels/file](#).

FedNav. 2017. Shipping lines expanding Canadian Arctic operations. FedNav Website [online]: Available from [fednav.com/en/media/shipping-lines-expanding-canadian-arctic-operations](#).

Ford JD. 2009. Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: a case study from Igloodik, Nunavut. *Regional Environmental Change*, 9(2): 83–100. DOI: [10.1007/s10113-008-0060-x](#)

Franz-Warkentin P. 2019. Grain leaves Churchill for the first time in four years. Manitoba Cooperator [online]: Available from [manitobacooperator.ca/daily/grain-leaves-churchill-for-first-time-in-four-years](#).

Fritt-Rasmussen J, Wegeberg S, Gustavson K, Sørheim KR, Daling PS, Jørgensen K, et al. 2018. Heavy fuel oil (HFO), review of fate and behaviour of HFO spills in cold seawater, including biodegradation,

environmental effects and oil spill response. Nordic Council of Ministers, Copenhagen, Denmark [online]: Available from norden.diva-portal.org/smash/get/diva2:1259220/FULLTEXT01.pdf.

Frizzell S. 2019. Environmental group asks to suspend Baffinland mine's approval process. CBC News [online]: Available from cbc.ca/news/canada/north/baffinland-phase-2-hearings-oceans-north-1.5345336.

George J. 2017. Heavy fuel oil ban would raise costs for Nunavut, shipping firms say. Nunatsiaq News [online]: Available from nunatsiaq.com/stories/article/65674heavy_fuel_oil_ban_would_up_costs_for_nunavut_shipping_company_says/.

George J. 2018. Nunavut Inuit org joins call for Arctic ban on heavy fuel oil. Nunatsiaq News [online]: Available from nunatsiaq.com/stories/article/65674nti_joins_in_call_for_arctic_hfo_ban/.

George J. 2019a. Push continues to phase out heavy fuel oil in the Arctic. Nunatsiaq News [online]: Available from nunatsiaq.com/stories/article/push-to-phase-out-heavy-fuel-oil-in-the-arctic-continues/.

George J. 2019b. Grays Bay road and port gets going again. Nunatsiaq News [online]: Available from nunatsiaq.com/stories/article/grays-bay-road-and-port-gets-on-the-go-again/.

ICC. 2019. ICC Canada brings Inuit message to London IMO meeting: time to ban HFO's in Arctic shipping. Inuit Circumpolar Council Canada, Ottawa, Canada [online]: Available from inuitcircumpolar.com/press-releases/icc-canada-brings-inuit-message-to-london-imo-meeting-time-to-ban-hfos-in-arctic-shipping/.

IMO PPR 7/8. 2019. Reduction of the impact on the Arctic of black carbon emissions from international shipping. Submitted by Finland and Germany. Sub-Committee on Pollution Prevention and Response [online]: Available from euractiv.com/wp-content/uploads/sites/2/2020/01/PPR-7-8-Initial-results-of-a-Black-Carbon-measurement-campaign-with-emphasis-on-the-impact-of-the...-Finland-and-Germany.pdf.

IMO PPR7/INF.14. 2019. Development of measures to reduce risks of use and carriage of heavy fuel oil as fuel by ships in Arctic waters. Submitted by Norway. Sub-Committee on Pollution Prevention and Response [online]: Available from transportstyrelsen.se/contentassets/50c7b4bb5b894a31b7892f0f379fe2db/7-inf14.pdf.

IMO PPR7/INF.19. 2019. Development of measures to reduce risks of use and carriage of heavy fuel oil as fuel by ships in Arctic waters. Submitted by the United States. Sub-Committee on Pollution Prevention and Response [online]: Available from transportstyrelsen.se/contentassets/50c7b4bb5b894a31b7892f0f379fe2db/7-inf19.pdf.

International Maritime Organization (IMO). XXXX [online]: Available from imo.org/en/MediaCentre/HotTopics/polar/Documents/POLAR%20CODE%20TEXT%20AS%20ADOPTED.pdf.

Inuit Impact Benefit Agreement. 2019. Tallurutiup Imanga National Marine Conservation Area Inuit Impact Benefit Agreement [online]: Available from qia.ca/wp-content/uploads/2019/09/2019-08-01_TINMCA-IIBA_FULLY-SIGNED-1.pdf.

Lack D. 2017. Investigation of appropriate control measures (abatement technologies) to reduce Black Carbon emissions from international shipping. Report to IMO [online]: Available from transportstyrelsen.se/contentassets/516e7989918b46c28fc8b81106fc79ae/5-inf7.pdf.

MEPC 72/11/1. 2018. Proposal to ban heavy fuel oil use and carriage as fuel by ships in Arctic waters. Presented to MEPC 72nd Session [online]: Available from transportstyrelsen.se/contentassets/57f800efae134fe0af0808d2773a14f2/72-11-1.pdf.

MEPC 72/11/4. 2018. Comments on document MEPC 72/11/1 on measures to reduce risks of use and carriage of heavy fuel oil as fuel by ships in Arctic waters. Presented to MEPC 72nd Session [online]: Available from transportstyrelsen.se/contentassets/57f800efae134fe0af0808d2773a14f2/72-11-4.pdf.

MEPC 72/17. 2018. Report of the Marine Environment Protection Committee on its 72nd Session [online]: Available from crs.hr/Portals/0/docs/eng/imo_iacs_eu/imo/mepc_reports/MEPC%2072%20-%20Report.pdf?ver=2018-06-29-140230-617.

Natural Resources Canada (NRCan). 2019. Contains information licensed under the Open Government Licence—Canada [online]: Available from open.canada.ca/en/open-government-licence-canada.

Niu H, Lee K, Boufadel MC, Zhao L, and Robinson B. 2014. In situ oil spill countermeasures in ice-infested waters: a modeling study of the fate/behaviours of spilled oil. *In* International Oil Spill Conference Proceedings. Vol. 2014, pp. 1215–1225. DOI: [10.7901/2169-3358-2014.1.1215](https://doi.org/10.7901/2169-3358-2014.1.1215)

NTI. n.d. About [online]: Available from tunnngavik.com/about/.

Oeder SK, Kanashova T, Sippula O, Sapcariu SC, Streibel T, Arteaga-Salas JM, et al. 2015. Particulate matter from both heavy fuel oil and diesel fuel shipping emissions show strong biological effects on human lung cells at realistic and comparable in vitro exposure conditions. *PLoS ONE*, 10(6): e0126536. PMID: [26039251](https://pubmed.ncbi.nlm.nih.gov/26039251/) DOI: [10.1371/journal.pone.0126536](https://doi.org/10.1371/journal.pone.0126536)

Parks Canada. 2019. National marine conservation areas—where is Tallurutiup Imanga. Parks Canada, Government of Canada, Gatineau, Canada [online]: Available from pc.gc.ca/en/amnc-nmca/cnamnc-cnnmca/tallurutiup-imanga/emplacement-location.

Pavlenko N, Comer B, Zhou Y, Calrk N, and Ruhterford D. 2020. The climate implications of using LNG as a marine fuel. Working Paper. International Council on Clean Transportation, Washington, DC: USA [online]: Available from theicct.org/sites/default/files/publications/Climate_implications_LNG_marinefuel_01282020.pdf.

Pelletier JF, and Guy E. 2015. Supply and demand for the Eastern Canadian Arctic Sealift. *Maritime Policy & Management*, 42(7): 669–681. DOI: [10.1080/03088839.2014.925594](https://doi.org/10.1080/03088839.2014.925594)

Pizzolato L, Howell S, Dawson J, Laliberté F, and Copland L. 2016. The influence of declining sea ice on shipping activity in the Canadian Arctic. *Geophysical Research Letters*, 43(12): 146–154. DOI: [10.1002/2016GL071489](https://doi.org/10.1002/2016GL071489)

Pizzolato L, Howell SE, Derksen C, Dawson J, and Copland L. 2014. Changing sea ice conditions and marine transportation activity in Canadian Arctic waters between 1990 and 2012. *Climatic Change*, 123(2): 161–173. DOI: [10.1007/s10584-013-1038-3](https://doi.org/10.1007/s10584-013-1038-3)

Power EM. 2008. Conceptualizing food security for Aboriginal people in Canada. *Canadian Journal of Public Health*, 99(2): 95–97. PMID: [18457280](https://pubmed.ncbi.nlm.nih.gov/18457280/) DOI: [10.1007/BF03405452](https://doi.org/10.1007/BF03405452)

Prior S, and Walsh D. 2018. A vision for a heavy fuel oil-free Arctic. *Environment: Science and Policy for Sustainable Development*, 60(6): 4–11. DOI: [10.1080/00139157.2018.1517515](https://doi.org/10.1080/00139157.2018.1517515)

Roy B, and Comer B. 2017. Alternatives to heavy fuel oil use in the Arctic: economic and environmental tradeoffs. The International Council on Clean Transportation, Washington, DC, USA [online]: Available from theicct.org/sites/default/files/publications/Arctic-HFO-alternatives_ICCT_Working-Paper_19042017_vF_corrected_0.pdf.

Sevunts L. 2020. Canada plans to support ban on heavy fuel oil in Arctic shipping. Radio Canada International [online]: Available from rcinet.ca/en/2020/02/13/canada-plans-to-support-ban-on-heavy-fuel-oil-in-arctic-shipping/.

Smith LC, and Stephenson SR. 2013. New trans-Arctic shipping routes navigable by midcentury. *Proceedings of the National Academy of Sciences of the United States of America*, 110(13): E1191–E1195. PMID: [23487747](#) DOI: [10.1073/pnas.1214212110](#)

Stephenson SR, Smith LC, Brigham LW, and Agnew JA. 2013. Projected 21st-century changes to Arctic marine access. *Climatic Change*, 118(3–4): 885–899. DOI: [10.1007/s10584-012-0685-0](#)

The Arctic Commitment. 2017. The Arctic Commitment [online]: Available from hfofreearctic.org/en/arctic-commitment/.

Transport Canada. 2019. Development of measures to reduce risks of use and carriage of heavy fuel oil as fuel by ships in Arctic waters [online]: Available from tc.gc.ca/documents/IMO_HFO_SUBMISSION_-_DECEMBER_2019-ACCESSIBLE.pdf.

United States-Canada Joint Arctic Leaders' Statement. 2016. United States-Canada Joint Arctic Leaders' Statement [online]: Available from pm.gc.ca/en/news/statements/2016/12/20/united-states-canada-joint-arctic-leaders-statement.

Vard Marine Inc. 2016. Arctic fuel switching impact study. Report to WWF-Canada [online]: Available from d2akrl9rvxl3z3.cloudfront.net/downloads/Arctic_Fuel_Cost_Comparison_report_Oct_11_2016.pdf.

Wesche S, and Chan HM. 2010. Adapting to the impacts of climate change on food security among Inuit in the western Canadian Arctic. *EcoHealth*, 7: 361–373. PMID: [20680394](#) DOI: [10.1007/s10393-010-0344-8](#)

Winnes H, and Fridell E. 2009. Particle emissions from ships: dependence on fuel type. *Journal of the Air & Waste Management Association*, 59(12): 1391–1398. PMID: [20066904](#) DOI: [10.3155/1047-3289.59.12.1391](#)